Monitoring Seasonal Dynamics of Arid Land Vegetation Using AVIRIS Data

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1. Introduction

The study of land vegetation cover conditions represents a major part of earth system science whether one is considering energy, water, carbon and nutrient cycles. Vegetation vigor, cover status and seasonal dynamics can affect many hydrologic factors on the regional to global scale, such as surface albedo, surface sensible and latent heat exchanges, rainfall infiltration , runoff and erosion. Thus plants have a major impact on inputs to ground water and surface hydrology, water, energy and cycling of the nutrients through the entire hydrologic cycle. Morever, vegetation cover is also a sensitive indicator of carbon status (storage and release). Change in the carbon status of plant communities may result in potential of insect outbreak and influence amount of carbon available to atmosphere. As one of the "forcing agents", concentration of carbon (e.g. CO_2) and its change in atmosphere play an important role on "greenhouse" effects. Therefore accurate estimation of land vegetation cover conditions and seasonal dynamics will improve the hydrologic modelling quality for surface hydrologic processes, evapotranspiration (ET) and other hydrologic variables as well as the estimation of carbon flux between the land surface and the atmosphere. Approximately 1/3 of land surface on the earth is arid and semi-arid areas. Due to limited water supply, vegetation in these areas are more sensitive to climate change and have rapid response to human induced impacts. As earlier study indicated, the expansion and contraction of the Saharan desert can be detected by vegetation monitoring using AVHRR data. So accurate mapping of vegetation cover density and seasonal dynamics in arid lands will certainly benefit the understanding and modelling of global change.

Our previous study with AVIRIS data of a Monterey pine plantation in Jasper Ridge Biological Preserve, CA has shown that derivative approach is very effective at minimizing background material's impacts and enhancing weak vegetation signals centered at chlorophyll red-edge. The derivative-based green vegetation index (DGVI) derived from AVIRIS reflectance of the plantation accurately quantified the spatial cover variations of the pines ranging from 1% to 32%. But this Monterey pine plantation has relatively uniform background and only a single plant species - Monterey pine (*Pinus radiata*). Thus reliability and robustness of the DGVI for quantifying low cover levels of green vegetation need to be further tested with AVIRIS data in an area with more complicated background materials and mixed vegetation communities.

2. Study Area

Mono Lake region was selected as the study area for the project. The Mono Lake area has a wide variation in rock and soil characteristics including colors, components, and spectral signatures. This area is a semi-arid region with different vegetation density levels. Major vegetation types in the area include shrubs (e.g. bitterbrush, sagebrush and rabbitbrush), salt grass, and pine forest.

3. Data Acquisition and Analysis

A total of ten sampling stands were selected in the study area. One stand is located in a pumice surfaced area with no vegetation cover. Nine others are bitterbrush (*Purshia tridentata*), which was selected as a reference species for monitoring DGVI's performance. The ten sampling stands were measured of the leaf area index (LAI) in field during AVIRIS data acquisition. The LAI was defined in this study as the ratio of leaf area over projected area of canopy on the ground.

Two AVIRIS datasets of Mono Lake area were separately collected on August 20 and October 7 of 1992. The two images acquired at different seasons were registered to each other by linear transform warping. Both images covers same series of pre-selected calibration targets. Using gains and offsets derived from the calibration targets, the two images were calibrated to ground reflectance in the full AVIRIS spectral range by empirical line method. Although the green cover levels were low, the red-edge feature was well recognizable in the August AVIRIS reflectance spectra of the bitterbrush stands. After weather became colder in October, the red-edge magnitudes decreased and became subtle due to loss of green leaves.

Before applying derivative, a low pass filter called Blackman window was used to smooth the reflectance spectra of the ten sample stands. The first and second order derivative reflectance spectra were then calculated using spectral distance between every other band as derivative interval. Using equations (1) and (2), both 1DL_DGVI (1st order DGVI derived using local baseline) and 2DZ_DGVI (2nd order DGVI derived using zero baseline) were generated.

$$1DL\_DGVI = \sum_{\lambda_1}^{\lambda_n} |\rho'(\lambda_i) - \rho'(\lambda_1)|\Delta\lambda_i \qquad (1)$$

$$2DZ\_DGVI = \sum_{\lambda_1}^{\lambda_n} |\rho''(\lambda_i)|\Delta\lambda_i \qquad (2)$$

In equations (1) and (2), i represents band number and λ_i represents center wavelength at the ith band. λ_1=626.9 nm (band 25) and λ_n=792.9 nm (band 45). The ρ, ρ', and ρ'' represent reflectance, 1st and 2nd order derivative reflectance, respectively.

Linear regression results exhibited strong linear relationship between the 2DZ_DGVI and LAI values of the ten sampling stands, having r^2 values greater than 0.93 for both AVIRIS datasets. However, the linearity between the 1DL_DGVI and LAI values appeared very poor due to contribution from negative derivatives of gravel materials in the barren areas to the calculation of the 1DL_DGVI. To correct the errors introduced by the negative derivatives of the gravel materials, the definition for the 1DL_DGVI was modified. The modified 1DL_DGVI (i.e. 1DL_MDGVI) is expressed in equation (3).

$$1DL\_MDGVI = \sum_{\lambda_1}^{\lambda_n} [\rho'(\lambda_i) - \rho'(\lambda_1)] \Delta\lambda_i; \; if \; \rho'(\lambda_i) - \rho'(\lambda_1) \geq 0 \quad (3)$$

By linear regression, the 1DL_MDGVI demonstrated strong linear correlation with the LAI values of the ten sample stands. High r^2 values (≥ 0.92) were acquired for both AVIRIS datasets collected in August and October of 1992.

4. Results

On the pixel by pixel conversion basis, equations (2) and (3) were applied to entire scene of the two AVIRIS images. Comparing two green cover maps developed from the 1DL_MDGVI and 2DZ_DGVI using August AVIRIS data, similar distribution patterns appear in the maps. Similarity of the green vegetation distribution patterns also exists in the green cover maps derived from the October's 1DL_MDGVI and 2DZ_DGVI. But the overall green vegetation cover levels of the study area decreased in October.

Seasonal changes in green cover density can be quantitatively analyzed by differencing DGVI values acquired for different seasons. The difference DGVI was calculated from following equation:

$$Difference\ DGVI = October's\ DGVI - August's\ DGVI \quad (4)$$

In general, herbaceous species (e.g. salt grass) responded more sensitively to seasonal changes in the study area and had bigger drop in green cover density from August to October. Shrubs including bitterbrush and sagebrush changed less. The seasonal cover changes of shrubs were basically due to losing green leaves. The least change in cover density between the two dates happened in regions covered by Ponderosa pines (*Pinus ponderosa*).

5. Conclusion

Although background materials are more complex at Mono Lake, derivative approach still proved optimal in reducing background impacts on green vegetation signals across the red-edge region. The relative cover variations and vegetation health status of low vegetated regions with mixed plant species can be quantified by 2DZ_DGVI and 1DL_MDGVI with high accuracy. The cover change intensity due to change of seasons can also be easily derived from difference DGVI maps. Thus, DGVI could provide a practical and more accurate way for operational monitoring ecosystems in arid and semi-arid lands.

It has to be emphasized that analysis of hyperspectral data (e.g. AVIRIS) and development of DGVI should be based on ground reflectance spectra as opposed to the radiance spectra. Radiance spectra have instrument effects removed, but still contain solar irradiance and atmospheric effects which would impair the operation of any vegetation index. This has also been evaluated in this project.

6. Acknowledgements

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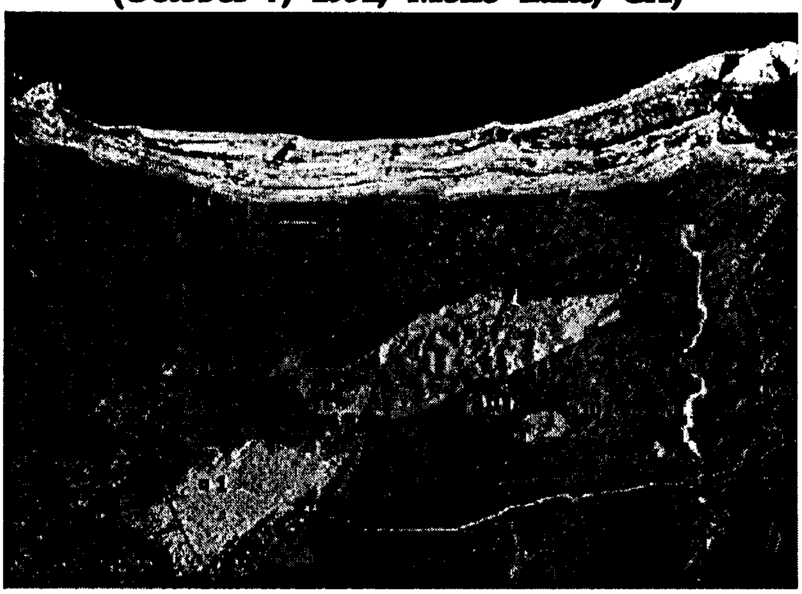
Table 1 LAI Values of 10 Bitterbrush Sample Sites

Sample Site	Sept. 4-5, 1992		Oct. 3-4, 1992	
	LAI	Std Dev	LAI	Std Dev
Site 1	0.000	0.000	0.000	0.000
Site 2	0.289	0.125	0.236	0.080
Site 3	0.526	0.208	0.431	0.124
Site 4	0.473	0.195	0.387	0.121
Site 5	0.496	0.210	0.406	0.132
Site 6	0.661	0.259	0.541	0.153
Site 7	0.318	0.128	0.261	0.078
Site 8	0.381	0.148	0.312	0.087
Site 9	0.426	0.174	0.349	0.106
Site 10	0.326	0.149	0.267	0.098

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
(August 20, 1992; Mono Lake, CA)

Red: 802.5 nm (CH. 46)
Green: 547.6 nm (CH. 17)
Blue: 439.3 nm (CH. 6)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
(October 7, 1992; Mono Lake, CA)



Red: 802.5 nm (CH. 46)
Green: 547.6 nm (CH. 17)
Blue: 439.3 nm (CH. 6)

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Figure 1. AVIRIS 3-band false color composite of the Mono Basin, CA. The top image was taken on August 20, 1992. The bottom image was acquired on October 7, 1992. Nine bitterbrush sample stands and a grey-colored pumice gravel stand (no.1) are displayed in both images.

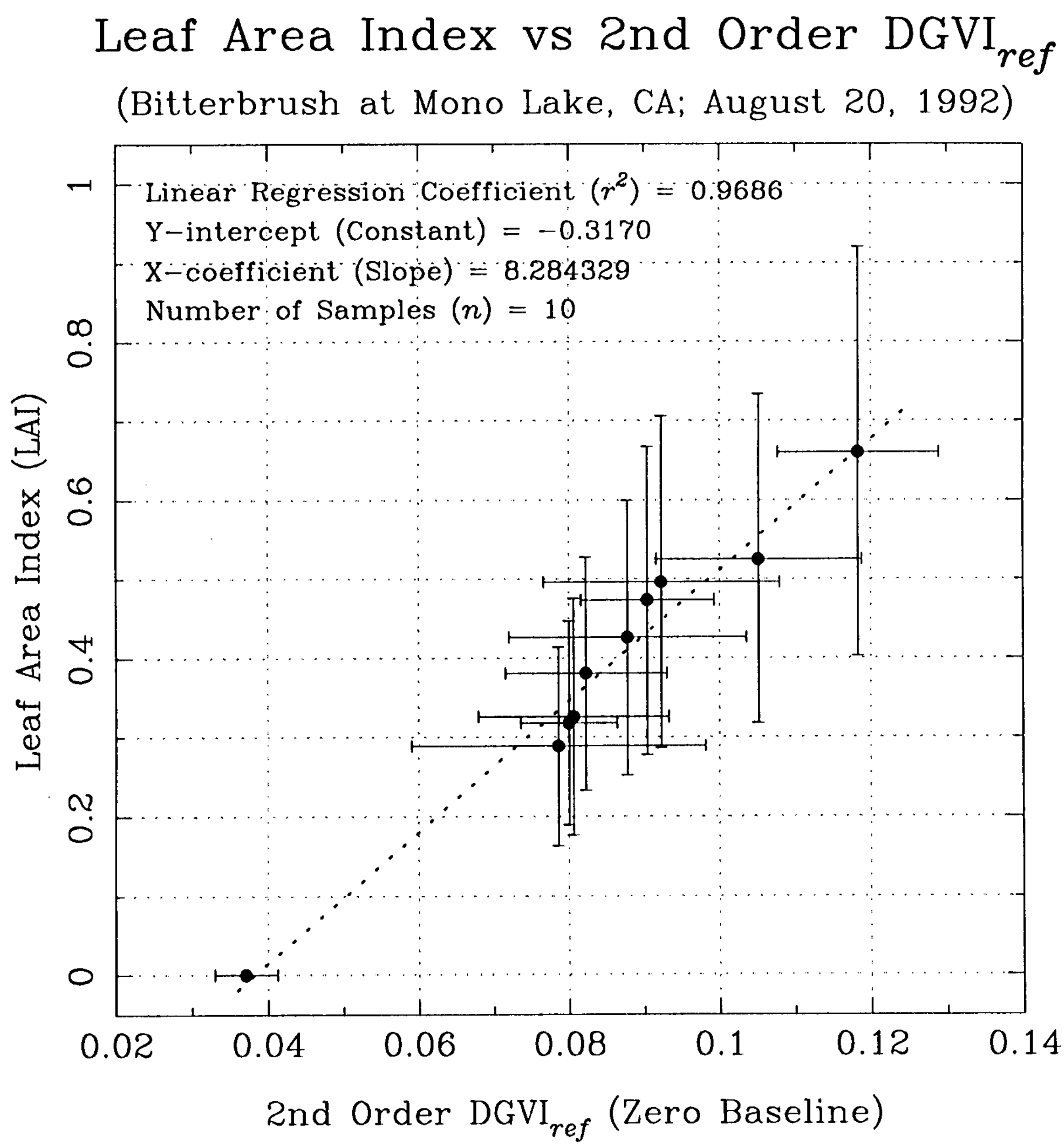

Figure 2. LAI values versus 2nd order DGVI calculated from 2nd order derivative reflectance of August 20, 1992 AVIRIS in reference to zero baseline (2DZ_DGVI). Horizontal and vertical bars represent standard deviations of the 2DZ_DGVI and LAI data.

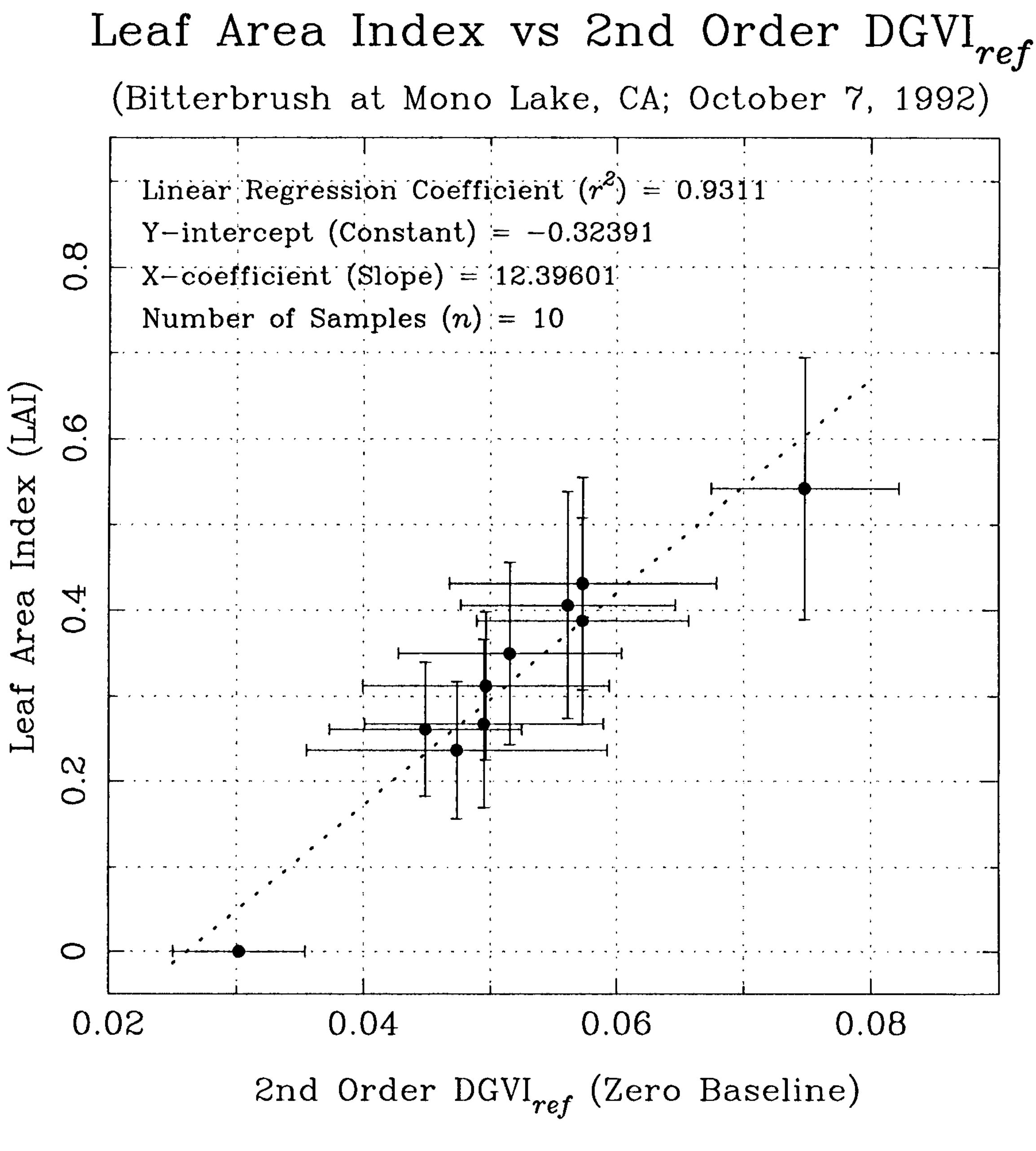

Figure 3. LAI values versus 2nd order DGVI calculated from 2nd order derivative reflectance of October 7, 1992 AVIRIS in reference to zero baseline (2DZ_DGVI). Horizontal and vertical bars represent standard deviations of the 2DZ_DGVI and LAI data.

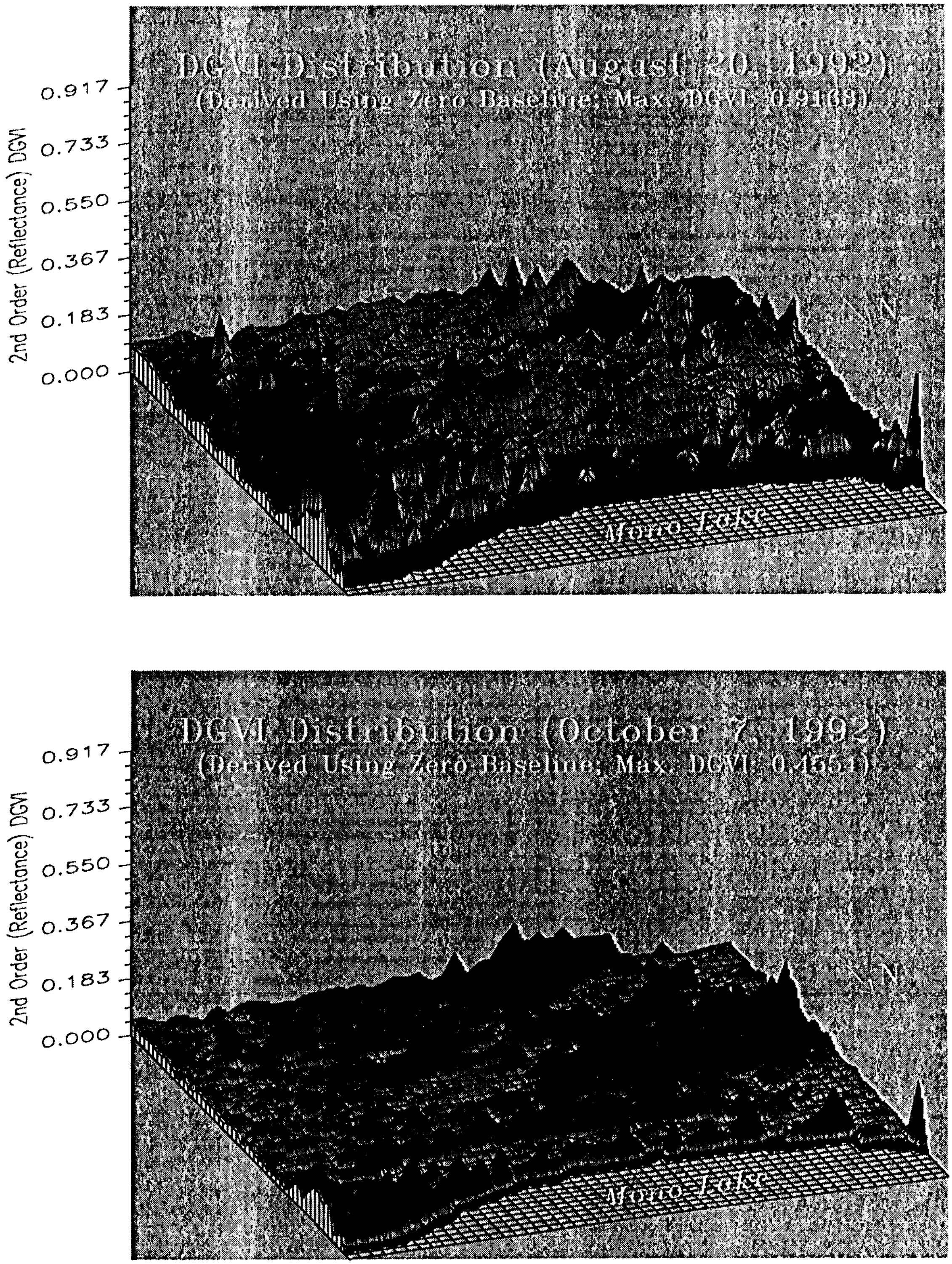

Figure 4. 3-D display of 2DZ_DGVI. Top map shows vegetation cover status on August 20, 1992. Bottom map displays vegetation cover status on October 7, 1992.

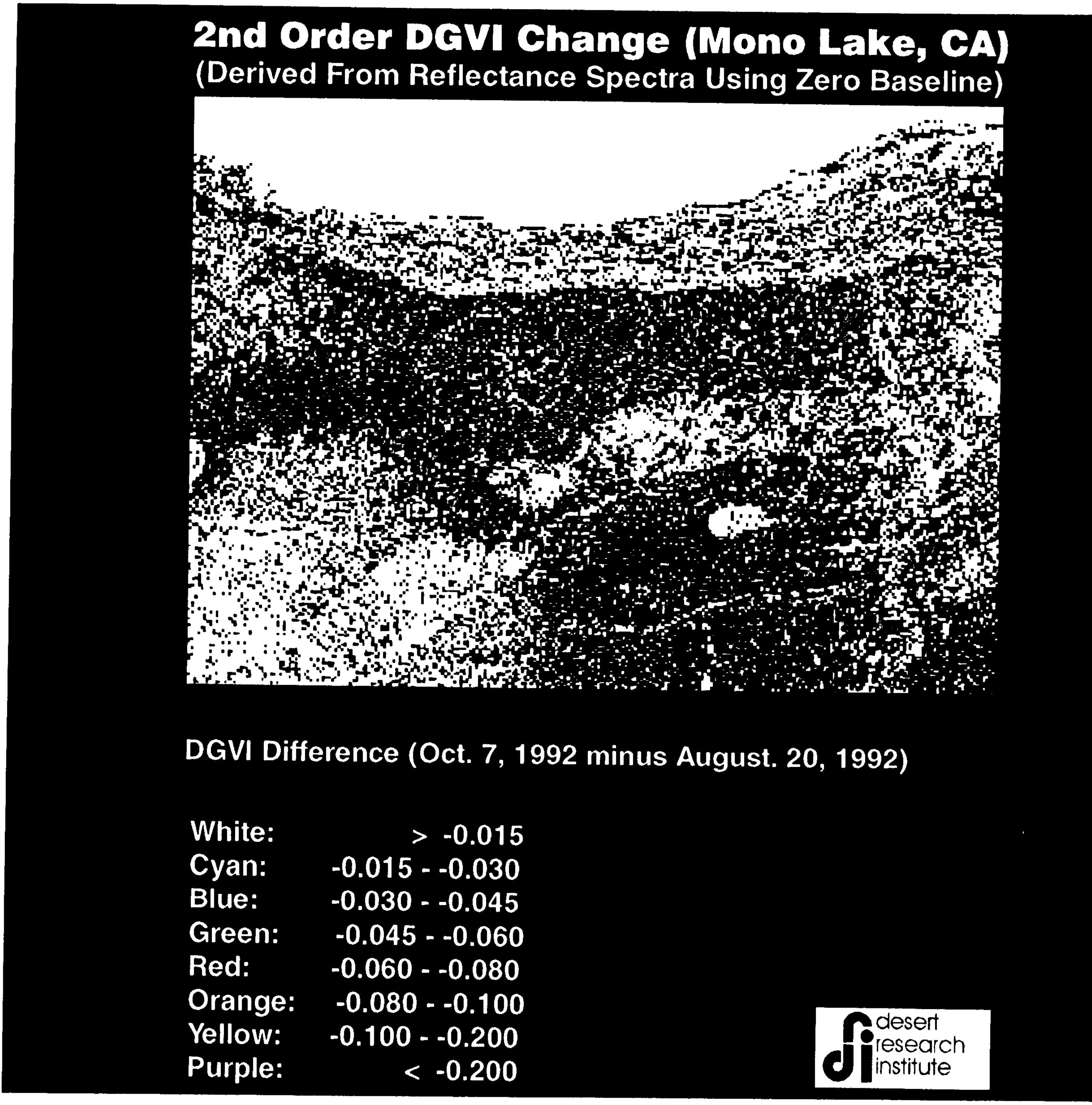

Figure 5. 2-D display of the difference 2DZ_DGVI distribution status. Seasonal change (decrease) in green vegetation cover of the study area is exhibited.